

Full Field Gas Phase Velocity Measurements in Microgravity

DeVon W. Griffin
NASA Lewis Research Center
Cleveland, OH

and

William Yanis
NYMA, Inc.
Cleveland, OH

Introduction

Measurement of full-field velocities via Particle Imaging Velocimetry (PIV) is common in research efforts involving fluid motion. While such measurements have been successfully performed in the liquid phase in a microgravity environment [1,2], gas-phase measurements have been beset by difficulties with seeding and laser strength. A synthesis of techniques developed at NASA LeRC exhibits promise in overcoming these difficulties.

Olson [3] used a pulsed smoke-wire technique to measure flow velocities over a solid fuel sample in microgravity. In this method, current was periodically passed through wire coated with an oil that produced smoke at low temperatures. The result was a series of smoke puffs, the velocity of which was assumed to match the local flow velocity. Data from flow velocities between 5 and 40 cm/sec were compared with plug flow velocities from rotameter measurements and found to agree well. Additionally, the technique was used to measure boundary layer velocities across the sample holder and were found to be within 3% of that predicted by Blasius theory.

While useful to characterize flows in that particular application, typical implementation of PIV involves forming the light from a pulsed laser into a sheet that is some fraction of a millimeter thick and 50 or more millimeters wide. When a particle enters this sheet during a pulse, light scattered from the particle is recorded by a detector, which may be a film plane or a CCD array. Assuming that the particle remains within the boundaries of the sheet for the second pulse and can be distinguished from neighboring particles, comparison of the two images produces an average velocity vector for the time between the pulses. If the concentration of particles in the sampling volume is sufficiently large but the particles remain discrete, a full field map may be generated.

Light Source

PIV systems often use pulsed lasers, generally Nd:YAG, that provide between 50 and 200 mJ per pulse. Such lasers, however, are currently incompatible with reduced gravity facilities, due to power consumption, size and lack of ruggedness [4]. To overcome those constraints, Big Sky Technologies developed for this project a Nd:YAG laser that pulses continuously at 30 Hz and in a burst mode where 4 pulses separated by 1 ms are produced every second. In the continuous mode, pulse energies may be as high as 42 mJ whereas 50 mJ is possible in the burst mode; typical pulse lengths are on the order of 12 ns. With these parameters and assuming a 50 mm wide light sheet, velocities between 3 and 1666 cm/sec may be measured. Efforts at LeRC have concentrated on the sub-buoyant region between 5 and 40 cm/sec.

Physically, the laser head is 318 mm long, 127 mm wide and 76 mm deep. Plumbing and electrical connections on the end add another 100 mm to the length. The cooling system and all electronics are housed in a rack of typical width and a total depth of 635 mm. The entire system is rated to +3 and -0.1 G and is operated on 10 amps of 110 VAC.

Based on those specifications, the entire unit may be flown on reduced gravity aircraft. At this date, hardware is being developed to support operation of this laser on NASA LeRC's DC-9 airplane. Current plans envision using one platform to support the laser and associated optics while fuel handling and ignition are provided by existing hardware. An enclosed beam path between the two rigs will prevent accidental exposure to the beam of this Class

IV laser. We are currently working with a vendor to determine if a tapered fiber could replace the lenses and tube as a beam delivery system. If the fiber meets the manufacturer's claims, it may also be implemented in NASA LeRC's 2.2 second drop tower, as is currently done with optical communications fiber.

Seed Particles and Delivery

Apocryphal stories abound concerning the need to periodically shock seeding chambers to insure a steady supply of seed to the flow of interest. While such procedures are easily implemented in normal gravity facilities, tending operation is not always possible in reduced gravity experiments on platforms such as sounding rockets. Therefore, we attempted to design a seeder that would be self-supplying. The seeder we developed features an inlet with a diameter of 0.1 mm and an outlet that can be as large as 6.3 mm. The device was made of extruded acrylic tubing to view the seed bed, thus facilitating rapid development of the seeder design. Depending on the gas, Reynolds numbers developed within the chamber are equal to or greater than 2000. The turbulent mixing, combined with an interior funnel, generate a seed bed that is continually agitated and generates a large seeding density within the chamber.

Current efforts are directed at velocity measurements in gas jet diffusion flames. To provide adequate measurement of the jet's flow velocity, seed particles must faithfully retrace the flowlines and be easily entrained. The particles that we have found that work best for this application are MicroSpherical Feathers sold by Osaka Gas America. [5] These SiO_2 particles are specifically engineered to be spherical and not agglomerate. The specific gravity is also low and on the order of 0.45 grams / cm^3 . Unfortunately, they presently cost \$1500 for 100 grams with a minimum order of 500 grams. We have tried three different diameters in our experiments with the 75 micron particles the optimal size for our application since they resist agglomeration better than the small 2.7 micron variety and are much more easily entrained than those with a diameter of 150 microns. Compared to other powders that may be used for such applications, such as 10 micron diameter TiO_2 or similarly-sized SiO_2 , MicroSpherical Feathers agglomerate less and appear to follow the flow much better.

Experiment Design

The light scattering physics underlying PIV was elucidated by many but is most often attributed to Gustav Mie [6]. To avoid *ad hoc* determination of system parameters such as laser power, detector sensitivity and lens speed, we have assembled a collection of computer codes that simplify this process. The first, developed by Edward Hovenac of NYMA, Inc. for use at LeRC in icing research calculates components of the scattering matrix using Mie theory. These results, when combined with propagation distance, can provide the irradiance level on the surface of the collecting lens. Additionally, integration of the data from Hovenac's program using software written by one of us (Griffin), produces the scattering cross section.

Before the illumination on the detector can be calculated, the irradiance at the object plane must be known. This requires knowledge of a combination of the laser energy/pulse, pulse duration and area over which the beam is spread. Design of the optics that produce a light sheet is required before the area is known. As before, avoidance of experimental determination of the correct optical prescription requires a computer code that models the optical path to sufficient precision. While most commercial lens design codes claim features for calculation of Gaussian beam parameters, they are typically based on the method of Kogelnik and Li [7] which masks a second solution to the Gaussian propagation equation. The net result is that the codes may not adequately represent beams used in light sheet systems. Therefore, a code based the equations of Seasholtz [8] was developed that allows the user to interactively search for parameters to produce the desired light sheet. Given the interactive nature of the formalism and program, at least one configuration can typically be found for almost any set of cylindrical lenses.

Data Reduction

Data reduction may be accomplished either via correlation of the two image fields or using the Particle Displacement Tracking method (PDT) developed at LeRC that was described previously [4,9]. Enhancements to the latter technique have allowed the use of only two frames to generate a velocity field. This software package also controls the acquisition of the image files for later analysis.

Planned Experiment Demonstration

A gas jet diffusion flame has been selected for the initial low-g demonstration. It will be located inside of a combustion chamber with the seeder previously described forming the base of the burner. When operating, light from the Big Sky laser enters the chamber through a window and illuminates the particles. Synchronization of the experiment is based on the 60 Hz timing pulse from a Xybion CID camera. This pulse is fed to a divide-by-2 circuit and then into a delay generator. Following the adjustable delay, a pulse is sent to the laser, causing it to fire. A notebook computer equipped with an expansion station and an Epix frame-grabber board uses the software previously described to grab every other field, coincident with the firing of the laser. Up to a 25 field sequence can thus be recorded, corresponding to almost 1 second of data. After the images are written to the hard drive, the experiment may be repeated immediately. By operating in this manner, a large data set may be collected and analyzed at a later time.

References

1. Ross, H., Miller, F., Schiller, D. and Sirignano, W.A., Third International Microgravity Combustion Conference, (1995).
2. Kamotani, Y., Ostrach, S. and Pline, A., *Physics of Fluids A*, **6**, 3601-3609 (1994).
3. Olson, S.L., *Combustion Science and Technology*, **76**, 233-249 (1991).
4. Greenberg, P.S., NASA CP 10113, pp. 61-66 (1992).
5. Ikeda, Y., Nishigaki, M., Ippommatsu, M., Hosokawa, S. and Nakajima, T., Sixth International Symposium on Applications of Laser Techniques to Fluid Mechanics, S32-2 (1993).
6. Mie, G., *Ann. Physik*, **30**, 59 (1908).
7. Kogelnik, H. and Li, T., *Applied Optics*, **5**, 1550-1567 (1966).
8. Seasholtz, R.G., NASA TN D-8297 (1977).
9. Wernet, M.P. and Edwards, R.V., *Applied Optics*, **29**, 3399-3417 (1990).